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REPORT ON JANUARY 1970 PERFORMANCE AND CALIBRATION TRIP TO

THE LUNAR LASER RANGING STATION AT McDONALD OBSERVATORY

S. K. Poultney

TECHNICAL REPORT NO. 70-087

2 March 1970

UNIVERSITY OF MARYLAND
DEPARTMENT OF PHYSICS AND ASTRONOMY
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Work Supported by NASA Grant NGR 21-002-109

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ABSTRACT

Performance of the detector package, Korad laser, receiver efficiency, and other portions of the McDonald Observatory Laser Ranging Station during January is reported upon. A summary of START and STOP LINE delay calibration is also included along with the results of the calibration procedure of University of Maryland, Department of Physics and Astronomy, Technical Report No. 70-049 for the vernier and TIM electronics.

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1. QUANTUM EFFICIENCY MEASUREMENTS

The quantum efficiency of PMT-1 (#08132) which has been in constant service since July was compared to that of PMT-3 (08029) at 6328Å on 30 January. Using a quoted RCA value of 7.1% for PMT-3 and assuming that PMT-1 does not behave abnormally between 6328Å and 6943Å, the author found that PMT-1 had a quantum efficiency of 6.7% (±1%) which is close to the value found in December (Technical Report No. 70-075 -- 6.6% (±1.8%)). Once PMT-1 is retired and another spare is obtained, it should be returned to Maryland for measurement at 6943Å.

Past measurements indicate that a tilted incident beam on the 31000F enhances its quantum efficiency by as much as 10%.

2. SINGLE PHOTOELECTRON LEVEL AND DARK CURRENT

During January, PMT-3 and a new 270 discriminator (#91) were tested at Maryland for single photoelectron level and correct adjustment for minimum walk. The walk at the adjustment selected appeared to be limited by poor termination of the light-emitting diode (HP 5082-4400) to about 1.4 nsec. An HV of 3000 volts was selected for single photoelectron operation. A free oscillation of the 270 was noticed at an improper setting of the walk adjust.

The 270 discriminator (#91) was brought to McDonald on January 30th and installed with PMT-1 after the delay in the old 270 (#69) and PMT-1 was calibrated. PMT-3 was brought to McDonald for a spare. Its dark current was quite high at room temperature at 3000 HV (i.e., ∿160 KHz). With the new 270 discriminator, PMT-1 had a dark current of 70KHz at room temperature which is about twice the December normal, but equal to the July normal. A star measurement is eagerly awaited to check for an increase in receiver efficiency and proof of 270 degradation with time.

Plans are being formed at Maryland to measure the PMT collection efficiency since this is the only unmeasured component of receiver efficiency and past work at Maryland has indicated that some PMTs are quite poor in this regard (e.g., 25%).

A fourth PMT (RCA 31000E) has been purchased as a spare. There were no adequate 31000Fs available to fulfill the warranty action on

PMT-2 by RCA. PMT-4 has a good quantum efficiency, very low dark current, a stable, high gain, and a flat, clear window. PMT-4 will be closely examined at Maryland.

3. DETECTOR PACKAGE COMPONENTS

A. Spatial Filter Components.

The beam-splitting prism was measured to have 94% reflectivity at 700nm. The 101mm lens in the spatial filter was measured to have a transmittance of 90% at 700nm and this particular lens was known to have a poor coating. The spherical aberration in the 101mm lens allowed only 94% of the light of an expanded He Ne laser beam to pass through a 100μ diameter pinhole when the pinhole was adjusted at the circle of least confusion. Such an adjustment is also used at McDonald. No details of the concave lens in the injection optics are known so that its spherical aberration is unknown. (Its focal length is much larger and so its spherical aberration may be negligible.)

B. 3Å Filter.

It was anticipated that the 3Å filter would probably drop ∿2Å in its center wavelength. With the measured temperature coefficient of 0.22 Å/°C, a new working temperature about 10°C above the old would be needed if measurements indicate such a drop.

The room temperature is often as much as 10°C below the 70°F of this last summer and so could cause trouble if ordinary resistors are used as references for the temperature control circuits. The control for the 3 Å has metal film resistors and so should not be affected. Little is known about the Perkin-Elmer filter circuit.

C. Perkin-Elmer Filter.

Technical Report No. 70-075 advised a temperature of 45°C based upon laser wavelength measurements.

The blocking filter of the Perkin-Elmer filter should be readjusted as explained in the instruction manual. It is a filter similar to the 3Å filter and may have shifted its passband center. Such a shift is not expected to alter the transmission drastically because the blocking filter has a width of about 10Å.

The temperature reference of this filter should be inquired about since room temperatures undergo large changes. A thermocouple probe was supplied for absolute measurements although the author does not recall any instructions for its use.

4. BEAM DIVERGENCE OF KORAD LASER

No measurements of the beam divergence of the Korad laser other than the return from the spider reflectors are being made.

5. UNIFORMITY OF LASER OUTPUT PULSE SHAPE AND AMPLITUDE

The use of the 417 leading-edge discriminator in the START LINE requires a fixed, steady pulse shape and amplitude which is the property of a TVR laser. However, the detection of the START pulse must also be well-behaved. The START pulse amplitude into the 417 discriminator had dropped by a factor of two between 15 December and 2 February. The drop could have occurred due to a real change in laser operating level, a change of detector bias voltage, a shift of detector filter (10Å) bandpass with temperature (or time), and a variation in pick-off energy due to a different circularizer prism (or just a different position). A combination of first and last causes probably explains the drop. Little is known theoretically about the pick-off scheme due to lack of information in the author's hands. However, a detection method must be developed to eliminate such sharp changes in amplitude and new equipment added to lessen their effect on the START time. The latter item would be a Constant Fraction Timing Discriminator (e.g. Ortec 453) with a wide dynamic range. The former item would consist of the following:

1. Once a week or after every prism change, RECALIBRATE.

2. At a known energy (use Korad calorimeter WITH chart recorder to correct for temperature drifts), adjust ND filters in KD1 detector such that power pulse has same amplitude as before.

The circularizer prism is changed because of internal damage. This damage looks to the author to be very similar to pictures[1/] of inclusion damage. If such is the case, a purer glass should be used for the prisms.

The present amplitude is 8 volts into 50Ω at the TEK 519 when the laser is operated at 3-3/4 joules. The Ortec 417 is set at 3.0.

6. FILTER/LASER WAVELENGTH MATCHING MONITOR

The filter/laser wavelength matching monitor has been temporarily inactivated for the following reasons:

a. Evidence of PMT degradation.

b. Electrical noise at time of laser firing.

c. Lack of easy adjustment on the sample mirror.

d. Lack of time to correct the above.

7. STAR MEASUREMENTS AND RECEIVER EFFICIENCY

a. Memo to D. G. Currie dated 16 February 1970.

UNIVERSITY OF MARYLAND

Department of Physics and Astronomy

INTRAMURAL

To: D. G. Currie

From: S. K. Poultney

Subject: Receiver Efficiency at McDonald

Date: February 16, 1970

A. This memo brings up to date the receiver efficiency numbers in Technical Report No. 957 for measurements made this summer.

1. Detector Package Efficiency.

PMT-1	8.6%	(measured, tilt has no effect)
Disc 270 - PMT (Cath Eff)	90 %	(reasonable assumption)
Prism	94 %	(measured)
Pinhole (≥400μ)	100 %	(measured)
Lenses	94 %	(measured, best set used)
3Å Filter	55 %	(manufacturer, peak)

$\tau_{DP} = 3.7\%$

2. GSFC Optics.

$\tau_G = 90\%$ (estimate excluding possible vignetting)

3. Receiver Efficency (best measure - with 3Å).

Measured on α Lyra $\tau_R = 0.4\%$

4. Conclusion: Telescope and Injection Optics Efficiency.

$$\tau_{T+O} = \frac{0.4\%}{\tau_{DP}\ \tau_G} = \frac{0.4\%}{3.7\% \times 90\%} = \frac{0.004}{0.037 \times 0.9}$$

$$\tau_{T+O} = 12\%$$

B. Since then, PMT-1 has degraded to 6.6% (slightly below 7.1% of PMT-2) as of February 1, 1970. The best receiver efficiency recently (January 28th) has been 24 kHz with αVIR, 0.7 Å filter, and 400μ(6") pinhole. Using a factor of 4 to adjust to 3Å filter standard, the receiver efficiency is 0.13%. Thus

$$\tau_{T+O} = 3.9\%.$$

(On 15 February a measurement of 240KHZ for A ORI was recorded with 0.7 Å filter. This measurement indicates a receiver efficiency of 0.26% on that date.)

C. Discussion.

1. There is an unexplained degradation between this summer and now in receiver efficiency.

2. The receiver efficiency this summer appeared low.

3. We should be able to increase return by 10 from now if we find the source of loss.

SKP/ls
cc: E. Silverberg
J. Mullendore
C. O. Alley

SKP

NOTE:

PMT-1	SN-08132
PMT-3	SN-08029
PMT-4	SN-06306

b. The assumption of 90% PMT collection and discriminator efficiency needs to be investigated because of the factor of 3 difference between expected telescope transmission and that inferred above. This factor of 3 is very similar to the discrepancy between expected and attained radar returns with the Maryland Backscatter Optical Radar.[2/] The factor of 3 drop from August to December is in addition to the possible low PMT collection efficiency.

c. The lack of star measurements makes it mandatory that an interim check on receiver efficiency be made using the moon. Knowing the spatial and spectral filters in use, one can normalize the lunar rate to a standard configuration. Use of the 400μ pinhole and 3Å filter is suggested for such a standard configuration. Normalization is achieved by pinhole area adjustment and by multiplying the rate by a nominal value of 4 whenever the 0.7Å filter is used. The past lunar data should be normalized and plotted as a function of lunar phase. If consistent, this data can be used to predict a normalized lunar rate on the day in question knowing the phase of the moon on that day. This check is independent of seeing problems.

8. SULSER 2.5c MAINTENANCE

On 1 February, the author found the Sulser 2.5c multiplier chain (and astrodata clock) to have been off for about 2 hours. The continued erratic behaviour of the multiplier made a re-tuning mandatory and the imminent visit of the Naval Observatory clock made it p ssible. The tuning procedure detailed in Technical Report No. 70-075 was followed. At first, the chain was extremely sensitive to disturbances, both physical and electrical. After tuning, the chain was very insensitive to disturbances and stayed on to bias voltages as low as 11 volts (24 volts is normal).

One experience in connection with the re-tuning is worth mentioning. The only adequate, variable dc voltage supply had been severely modified and had to be taken apart and rewired before the re-tuning could be done. This wait prolonged the temperature shock to the crystal frequency standard.

9. VERNIER AND TIM CALIBRATION

The calibration of the verniers and TIM of the ranging electronics is described in great detail in Technical Report No. 70-049 by C. A. Steggerda. It will be of value to review the calibration procedure especially since the author carried out the calibration during January. Upon my arrival on 30 January, the laser ranging operational group suspected that a problem existed in the ranging electronics based upon their version of a system check. The following approach proved effective in locating the problem.

First, a known interval (modulo 50 nsec) was produced per Technical Report No. 70-049 which started and stopped the ranging system with NIM pulses directly at the TPHCs. This interval was varied using the calibrated delay cables (10 nsec, 30 nsec, 40 nsec, and 50 nsec) in each vernier line alternately. In the January problem, the respective changes in the computer print-out did NOT correspond to the changes made in the timed interval.

Second, the vernier output voltages were displayed on an oscilloscope and at the same time sent to the Astroverter as usual. In this case, the vernier voltages in conjunction with the TIM read-out were as close to the timed interval as the oscilloscope photograph allowed.

Third, the linearity (and calibration) of the vernier-Astroverter was checked, using the TDG per Technical Report No. 70-049 in conjunction with the K program. This check showed no abnormal behaviour. If it had, the Astroverter check in Appendix I would have been used.

The diagnosis of the problem hinged upon the fact that in the first two checks, one had to use the interpretive program in the computer whereas the third check used the K program. The fault thus lay in the interpretive program that allows the station operators to be sure of acquisition at a particular time. The basic data is itself stored on magnetic tape and a precise range and confidence calculated much later. Two errors were found in the interpretive program; a basic one by J. D. Rayner and a substitution constant by W. Van Citters. Correction of these two errors allowed the interpretive program to accomplish its rough estimate of the ranges in real time. A third error of occasional noise starts in the unused second stop-vernier was cured by removing the second vernier. It is suggested that similar noise starts (due probably to shutter noise) might be causing problems in the other verniers. Ordinarily, the verniers should give no output unless stopped as well as started. In the typical ranging mode, the verniers continually receive stop pulses. Peculiarities that <u>DO</u> happen when no stop pulses occur are discussed in the next section.

The author's week trip ended before a definitive vernier and TIM calibration was made but the equipment was left in operating condition and most members of the operating group were familiar with the procedure. Frequent calibrations <u>MUST</u> be made in order to evaluate possible changes of vernier or Astroverter operation with time or, more importantly, with temperature.

10. SUMMARY OF START-STOP DELAY CALIBRATION

A. Present Calibration.

The main purpose of the January trip was to calibrate the delays in the start-stop lines, using a better light emitting diode. The HP 5082-4400 diode discussed in Technical Report No. 70-075 was used in conjunction with the Tektronix 109 pulser and the known delay cables. Work at Maryland had shown that, with electrical pulses whose full width was 1 nsec, the Tektronix 109 pulser operating at about a dial setting of 35 volts gave single photoelectron light levels with a 50Ω attenuator on the diode and no light attenuation at all. The previous light-emitting diode had allowed one to leave the Perkin-Elmer filter in place, but, with the HP 5082-4400, one had to place it directly in front of the PMT as at Maryland. This effect is probably due to impedance matching at the various diodes and the matching used at McDonald was still not optimum.

The start vernier was used in all measurements of delays. The 109 pulser was adjusted to give a negative pulse which was split so that one part started the vernier and the other part stopped the vernier after traversing the route of unknown delay. In this manner, the fast auxiliary cable (Belden No. 8214) delay was measured directly. A 10 nsec green calibrated cable was used in the start line. The K program read-out was converted to time using the approximate vernier calibration curve taken recently at McDonald by the operating group (per Technical Report No. 70-049). The result was 104 nsec (±0.5 nsec) and was limited by the vernier calibration. The start line delay, omitting the KD1 detector (since the light diode could not activate it), was found to be 90 nsec up to the start vernier at its present trigger level. The KD1 detector gives positive pulses whereas the Tektronix 109 gives negative pulses so that during this trip the negative input of the 417 discriminator was calibrated. The positive input was calibrated last trip and its value was quoted to be 93 nsec (±2 nsec). The new value for the auxiliary cable changes the quote to 91 nsec (±2 nsec). A modification of the start line detector discussed below will alleviate the required complicated calibration of the 417 discriminator by yielding negative start pulses. The 417 discriminator levels are given in Section 5.

The stop line cable delays were examined in a similar manner. A NIM pulse was produced by the Tektronix 109 and injected at the output of the Ortec 270. The delay from the output of the Ortec 270 to the vernier stop through the 403A was found to be 88 nsec (±0.5 nsec), again limited by vernier calibration. The previous measurement yielded a corrected 89 ± 2 nsec. The previous measurements, you will recall, were made by an oscilloscope and did not include actual vernier trigger levels.

The complete stop line delay was determined for PMT-1/DISC 69 and PMT-1/DISC 91 for a number of different HV bias voltages by sending the negative 109 pulse to the light diode immediately in front of the PMT. The Tektronix 109 pulser is adjusted to yield a 1 nsec pulse of amplitude such as to give a PMT output every ten or so pulses from the pulser. Here, the P program is convenient to use. One must, however, see that the vernier always receives a stop pulse for every start or else the print-out is garbage. One way to do this is to use the vernier true start output to stop itself at a much later time (through a B-16, for example). The P program ignores full-scale vernier outputs. (NOTE: The author would like to thank W. Van Citters for re-writing K and P programs to operate with the modified Astroverter.)

The results of the calibration of PMT-1 at HV 3200 with DISC 69 (December configuration) gave a jitter of ±1.5 nsec full-width limited most likely by light diode termination. The total delay from photocathode to vernier was 132 nsec assuming no delay in photo-emission of light diode. This value is considerably below the 147 nsec measured in December under adverse conditions. The inferred PMT/DISC delay of 44 nsec is closer to the value measured at Maryland in December. Delays for 3300 and 3400 HV can be supplied. In all cases, the delay in the Tektronix 109 start arm was adjusted to yield a mid-scale reading on the vernier by adding or subtracting a green calibrated delay cable.

In summary, the start line delay, excluding KD1 delay and using negative Ortec 417 discriminator, was found to be 90 ± 0.5 nsec. The stop line delay, including photo-emitter delay, was found to be 132 nsec with a single photo-electron level walk of ±1.5 nsec. Thus, a total of 42 ± 1.5 nsec must be subtracted from an observed range in addition to light path and other corrections (e.g. corrections per Technical Report No. 70-049). This present delay calibration should be used for all data taken with PMT-1 at HV 3200 and DISC 69 since December. PMT-1 and DISC 91 delays can be supplied if data was obtained with them. It is important to note that a B-16 may be substituted for the Tektronix 109 used above at the cost of a 10 nsec jitter in the stop line delay. If a Tektronix 111 is available, the stop line delay jitter would be about 3 nsec.

B. <u>Future Calibration (March Trip).</u>

A PMT will be used to provide the start signal so that a light diode and the Tektronix 109 pulser will suffice to calibrate the system completely. The PMT (a suitably biased RCA 8644) will yield a negative pulse which will use the negative input to the Ortec 417 discriminator (or Ortec 453 if available). Suitable attenuation will be provided such that the laser pick-off signal is the same amplitude as the calibration pulse. For single photo-electron measurements at the stop PMT, additional attenuation will be added between the light diode and PMT. The light diode will be physically moved to start and stop PMTs. A prompt signal from the Tektronix 109 will start the relevant vernier and the detector signal will stop it. Any delay in the light diode will cancel out. The procedure will be exactly as described in Section A above. The results of K and P program readings will be stored on magnetic tape under appropriate labels for later processing at Maryland. The accuracy on stop/start is expected to be ±0.5 nsec. The precision on stop is expected to be better than ±1.5 nsec using a better termination on the light diode.

A very important result of accumulated calibration data will be to determine whether or not the delay of the PMTs varies with age and temperature and whether or not the delay of the 270 DISC varies with age and temperature. Appendix II summarizes start/stop delay calibra-

11. REFERENCES

1. C. Young and R. Woodcock, "Laser-Induced Damage in Glass," ASTM STP 469, American Society for Testing and Materials, 1969, pp. 84-99.

2. E. C. Silverberg and S. K. Poultney, "Optical Radar Backscattering Above 30KM During April 1968," Technical Report No. 900, August 1968, University of Maryland, Department of Physics and Astronomy, pp. 25-27.

APPENDIX I: ASTROVERTER CHECK

C. A. Steggerda

Purpose:

1. To determine the linearity of the ADC and the operation of all the ADC bits.

2. To check the flags of channels 0, 1, 2 and check the computer interface.

Procedure:

1. Connect a DC power supply (H.P.s OK) capable of operation from 0 to +10 volts to the data line of channel 0. Connect the Rutherford B-16 pulser to the flag 0 line. The pulser should be programmed to give a +5 volt 5μ sec pulse on manual operation. Connect a digital voltmeter in parallel to the DC source voltage so that the voltage may be monitored. Set the voltage for a convenient number such as 100 m.v.

2. Load the K program by typing K.

3. Type 1 and increase the DC voltage 1 m.v.

4. Press the manual trigger on the B-16, a number should be typed on the teletype. The digital voltmeter reading should be recorded opposite the teletype number.

5. Go back to step 3 unless DC voltage is 150 m.v.

6. Plot the DC voltage as read by the digital voltmeter versus the DC voltage as recorded by the Astroverter. There should be a change in the Astroverter output every 2.5 millivolts.

7. Plot the Astroverter output versus DC voltage over the entire 0 to 10 volt range using 50 m.v. steps.

8. Repeat for channels 1 and 2.

APPENDIX II. START/STOP DELAY CALIBRATION PROCEDURE

A. Auxiliary Cable Delay Measurements (Monthly).

1. Shape pulse output of pulser to negative NIM size.

2. Start calibrated vernier with 10 nsec green cable.

3. Stop calibrated vernier with Belden Auxiliary cable ($\sim$104 nsec).

4. Address data by K3 and raise Sense Switch 3 to store data. Press 3 key five times.

5. Place 30 nsec green cable in stop line in addition to Belden auxiliary. Address data by K3 and raise Sense Switch 3 to store data. Press 3 key five times.

6. Replace 30 nsec green cable with 40 nsec green cable in addition to Belden auxiliary. Repeat address and store.

7. Replace 40 nsec green cable with 50 nsec green cable. Repeat address and store.

8. Replace 10 nsec green cable in start line with 30 nsec green cable. Repeat address and store in K3 locations.

B. Start-Line Delay (Daily).

1. Shape pulse output of pulser to 1 nsec width.

2. Start calibrated vernier with 70 nsec green cable to allow mid-range vernier reading. Attenuate with a 50Ω attenuator (e.g. GR874-63) if necessary.

3. Drive light diode at start PMT with Belden auxiliary cable (519 oscilloscope checks show that with proper hardware, the pulse can be split at a "T"). Ortec 417 output drives vernier stop.

4. Address data by K2 and raise Sense Switch 3 to store calibration data. Press 2 ten times.

5. If start PMT not available, reshape pulse output to mock KD1 output and inject at KD1 output. Do all else above as stated.

C. Stop-Line Delay (Daily).

1. Use same pulse as in B.

2. Start calibrated vernier with 120 nsec green cable to allow mid-range vernier reading.

3. Drive light diode at stop PMT with Belden auxiliary cable.

4. Address data by P500 and raise Sense Switch 3 to store data. Check that the stops are about 10% of pulser starts (reduce pulse amplitude if necessary), and that the vernier always receives a long stop as explained in Section 10.

APPENDIX III. VERNIER CALIBRATIONS WITH TDG

1. Trigger TDG by computer.

2. Start vernier with TDG start and stop vernier with TDG stop using equal length cables.

3. Address calibration data by K1 and raise Sense Switch 3 to store data. Press 1 five times for each TDG delay.

4. Set TDG from 10 nsec to 200 nsec in 10 nsec steps.

5. Repeat for each vernier. The computer labels each internal to program.